MICROFOCUSING OF THE FERMI@ELETTRA FEL BEAM WITH A K-B ACTIVE OPTICS SYSTEM: SPOT SIZE PREDICTIONS

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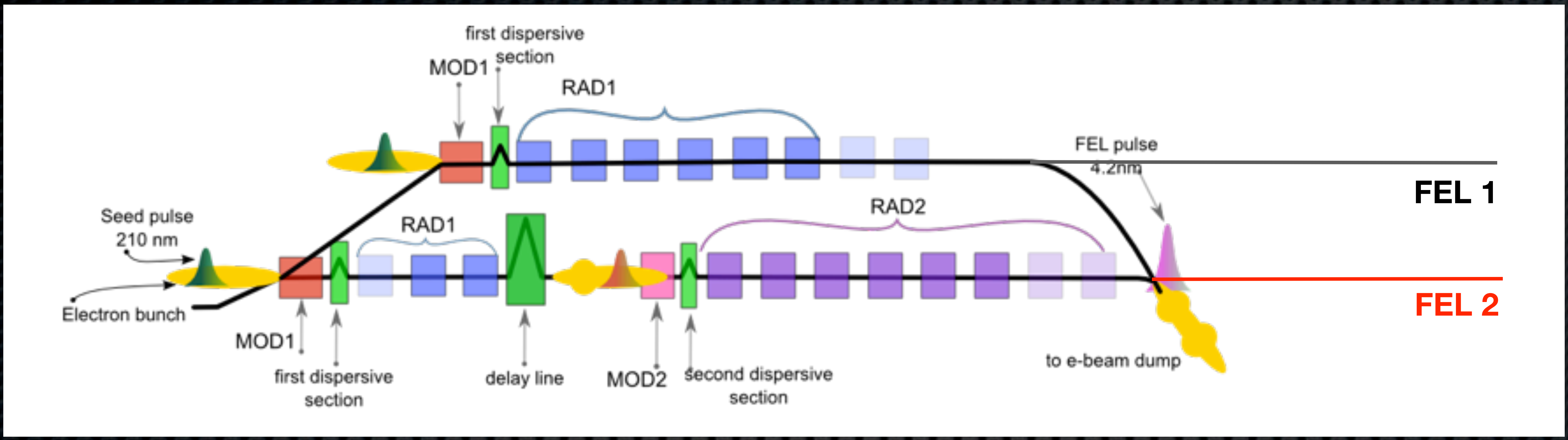
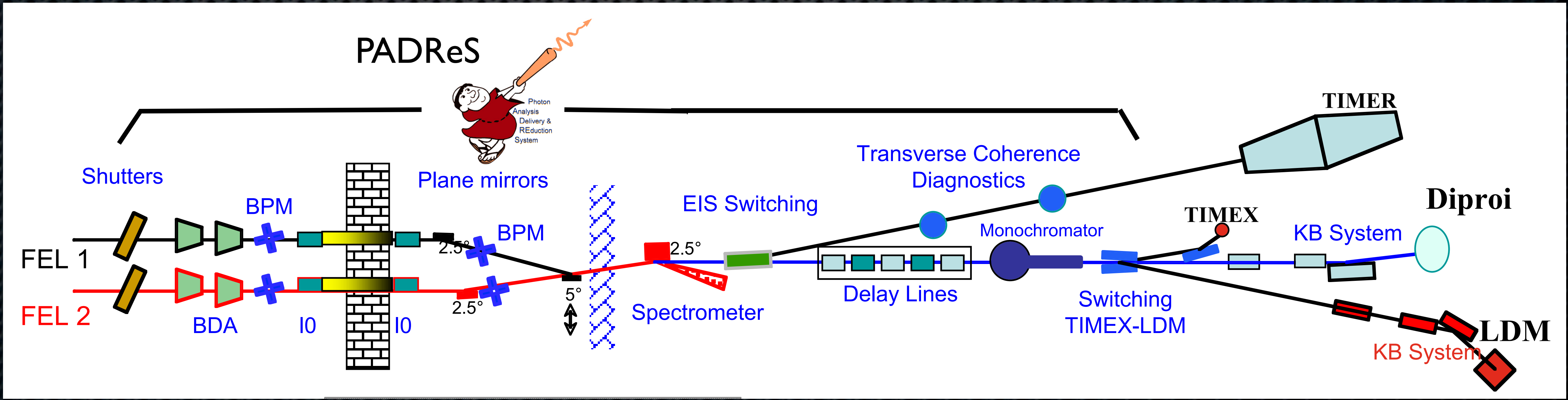
Photon Analysis Delivery & REduction System

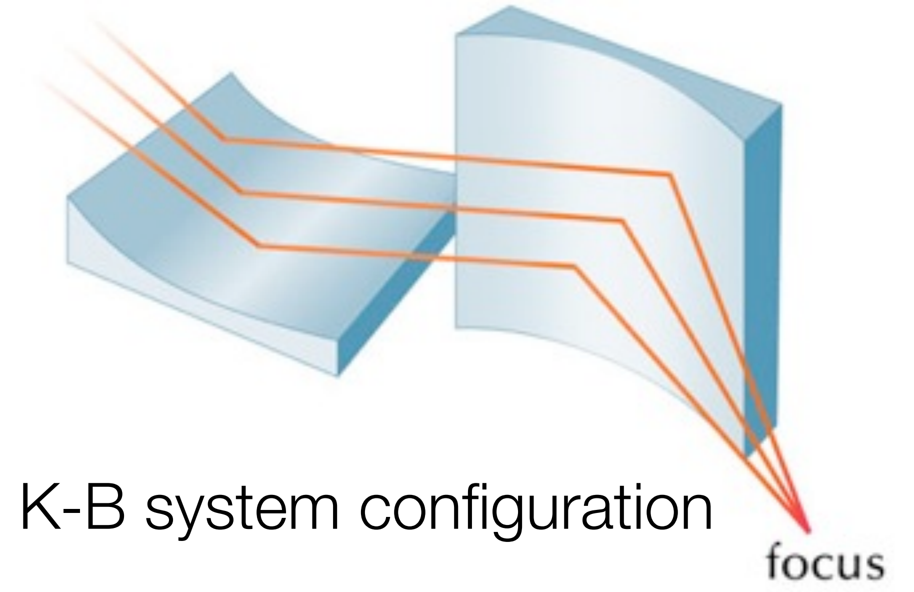
FERMI@Elettra seeded FEL

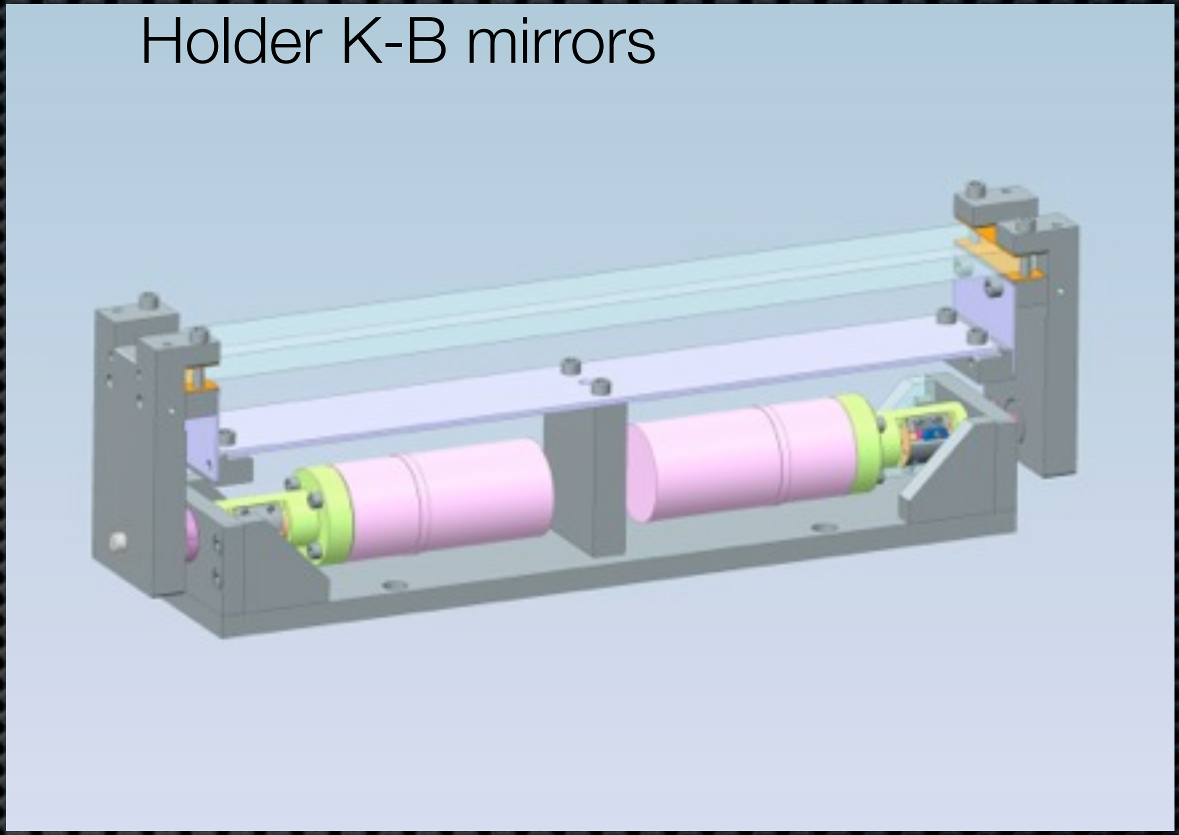


- FEL 1 from ~100 nm down to 20 nm - source distance (to spectrometer) 57.5 m
  Divergence σ(μrad) = 1.25 λ(nm) - Source dimension = 60 μm (sigma)
- FEL 2 from 20 nm down to ~4 nm - source distance (to spectrometer) 49.8 m
  Divergence σ(μrad) = 1.5 λ(nm) - Source dimension = 123 μm (sigma)



K-B active optic system - DiProI





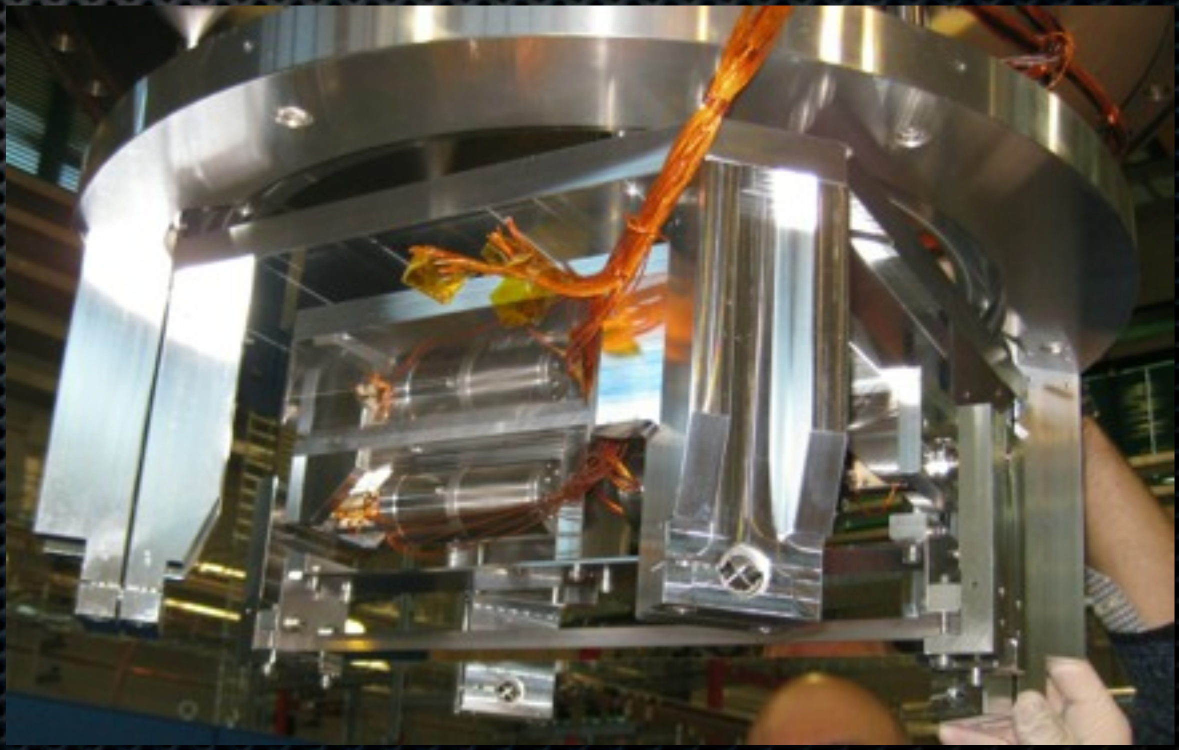
End-stations need high flux - great demagnification

K-B system advantages

- Decoupling vertical and horizontal beam components
- Thick ellipsoidal mirrors with the great demagnification request are difficult to realize

K-B bendable system advantages

- Focalization of the 2 sources at different distance with the same couple of mirrors
- Difficult realization of thick elliptical mirror with this demanding demagnification
- Improvement of the FEL beam wave-front

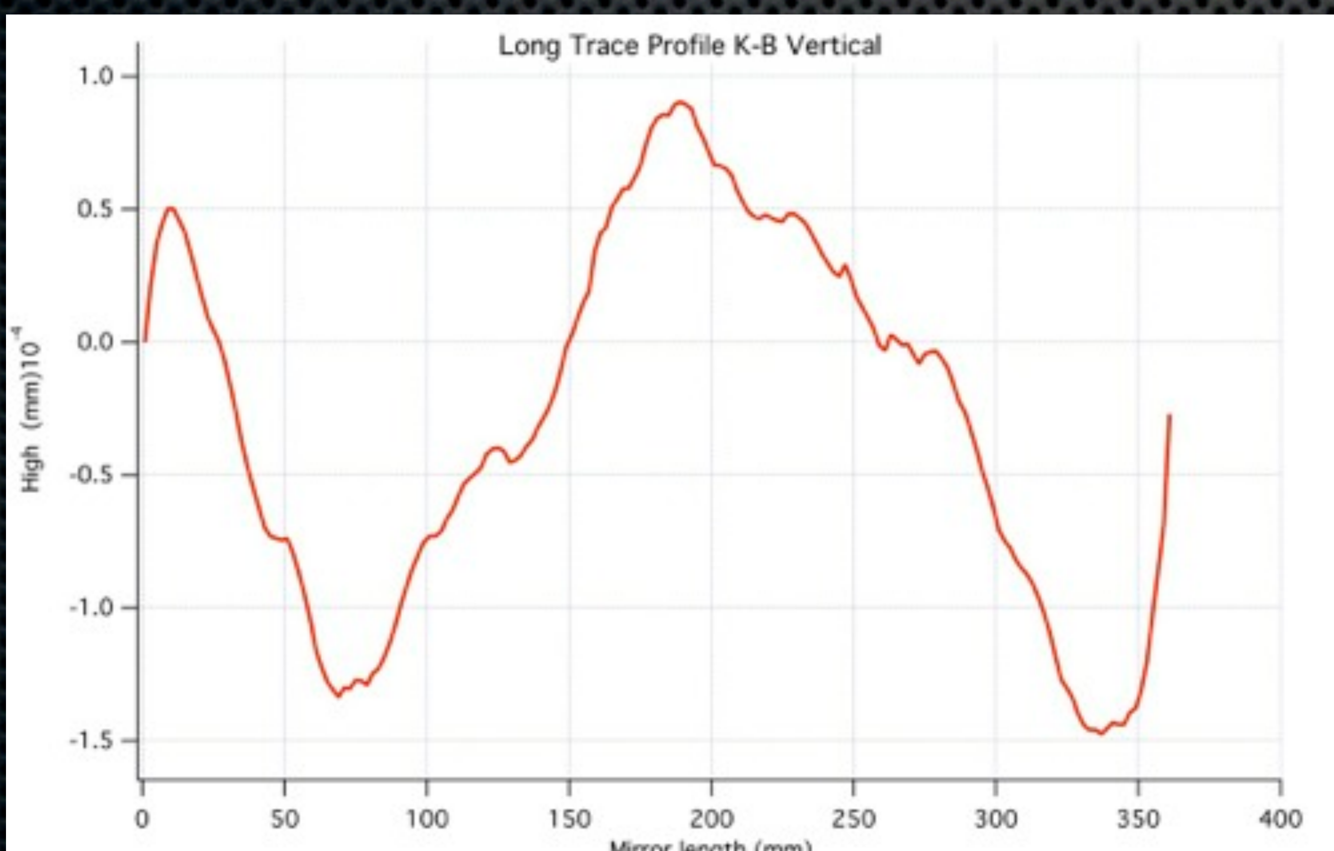


K-B active optic system - DiProI

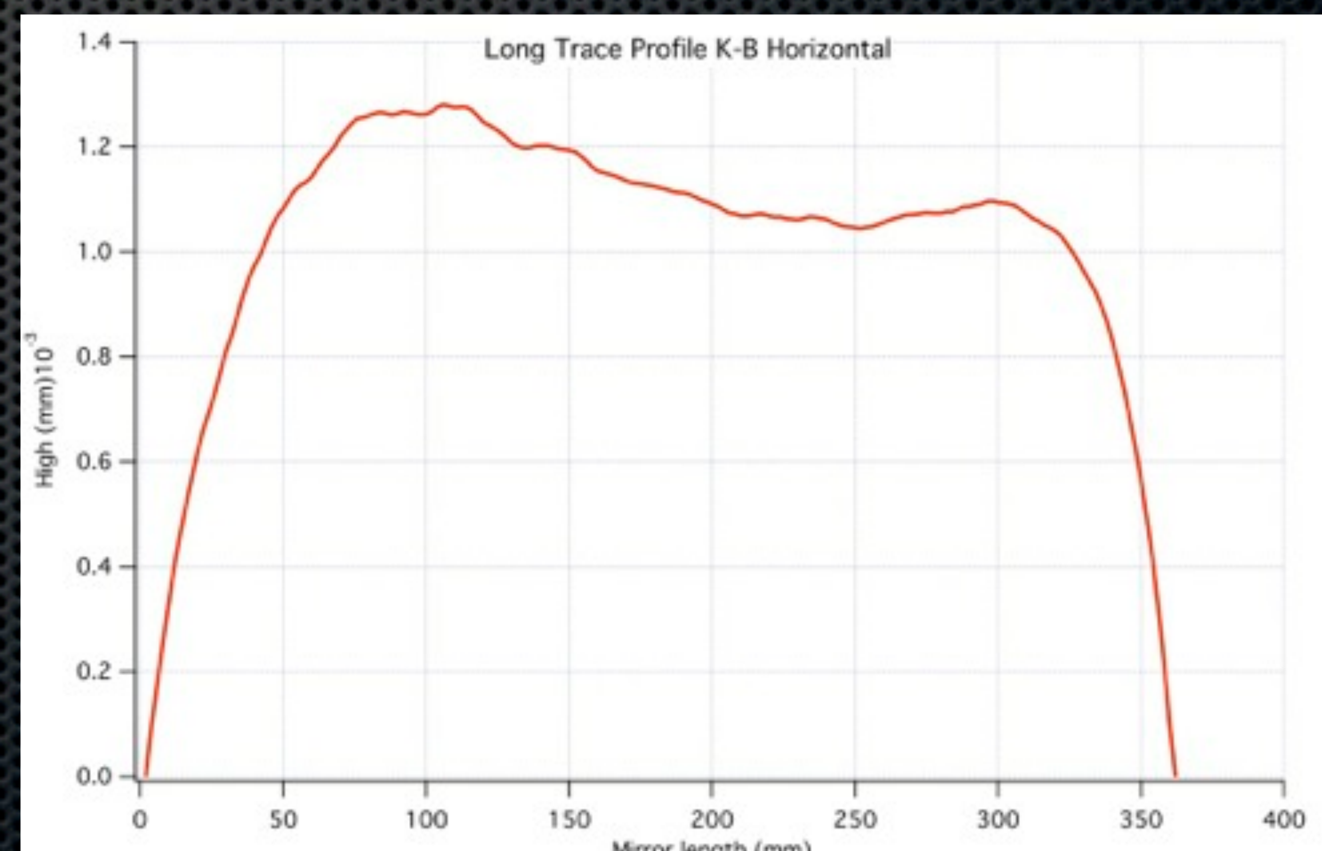
Profile surface characterization with Long Trace Profilometer

- LTP profile measurements 1mm step
- Best possible profile reached through the Adaptive Correction Tool software
- Measurements with Zygo interferometer and AFM - rms under specifications (<3A spatial range 2μm - 0.5mm)
- Proof of the system stability

K-B Vertical mirror - residual surface profile



K-B Horizontal mirror - residual surface profile



K-B active optic system - DiProI

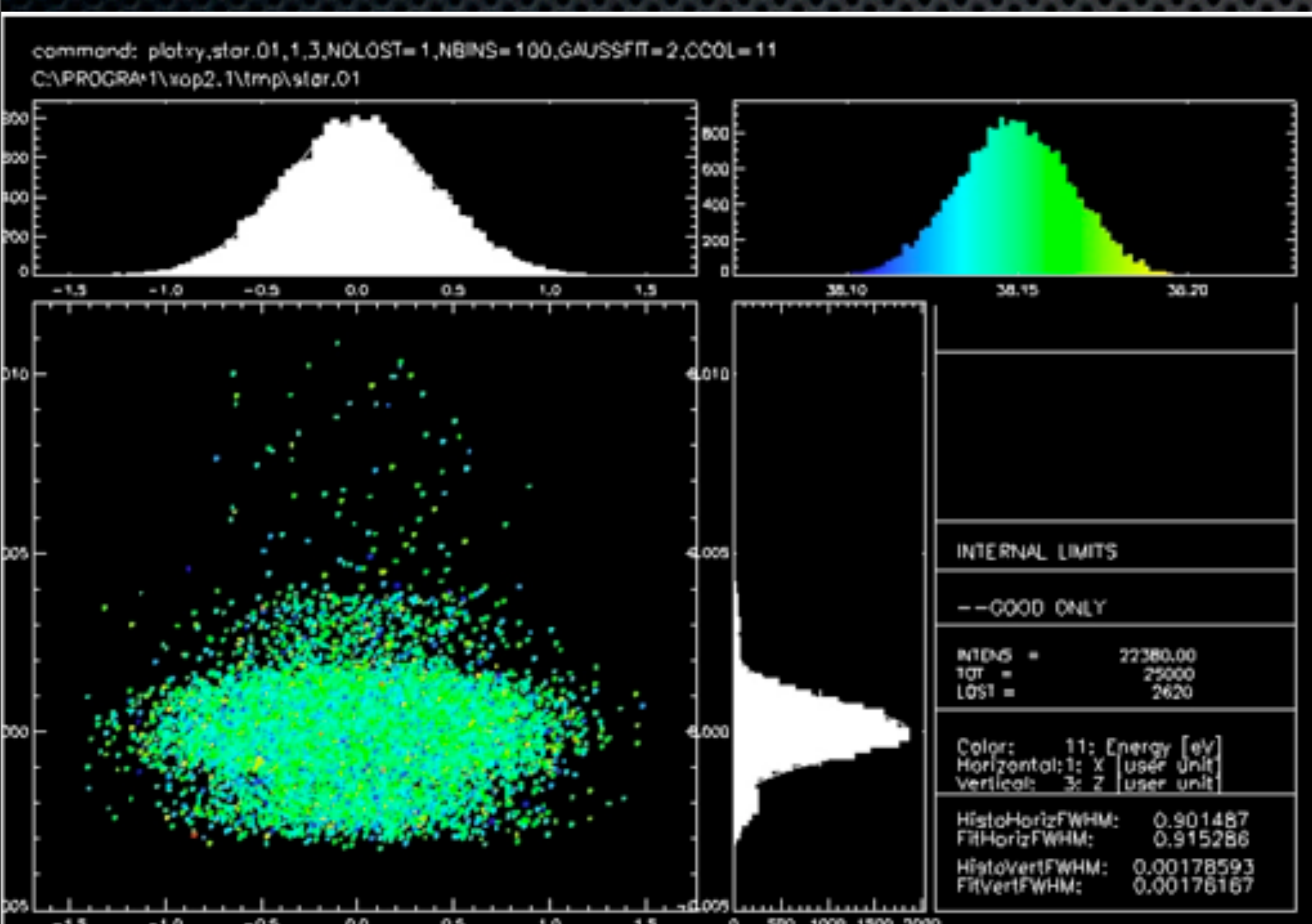
Ray tracing simulations with Shadow code

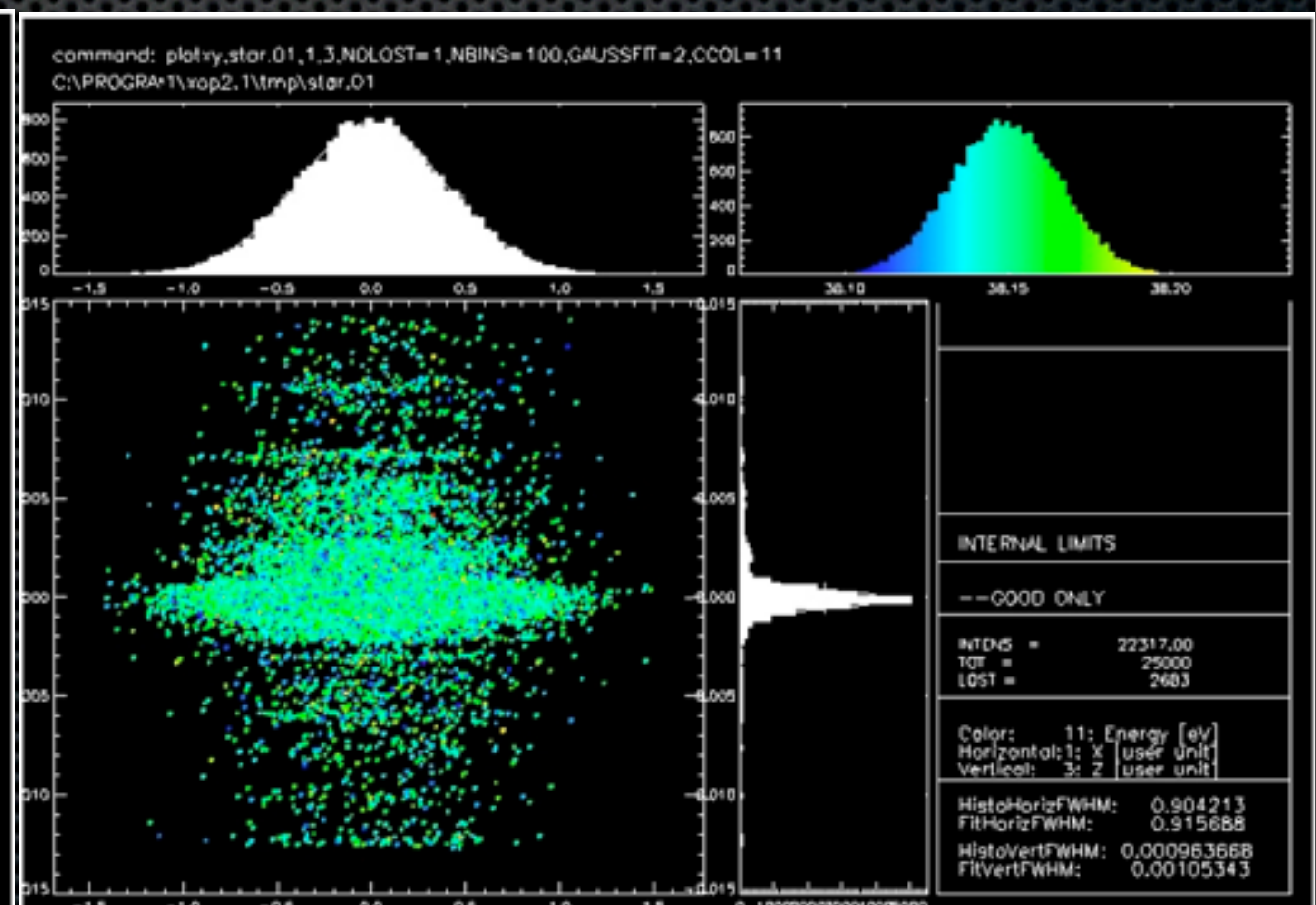
K-B vertical mirror at best focus (+2mm to the nominal focus)

$FWHM_{ray\text{-}tracing}$ = 18 μm

K-B horizontal mirror at best focus (-2mm to the nominal focus)

$FWHM_{ray\text{-}tracing}$ = 10.5 μm





Focal spot measurements - DiProl

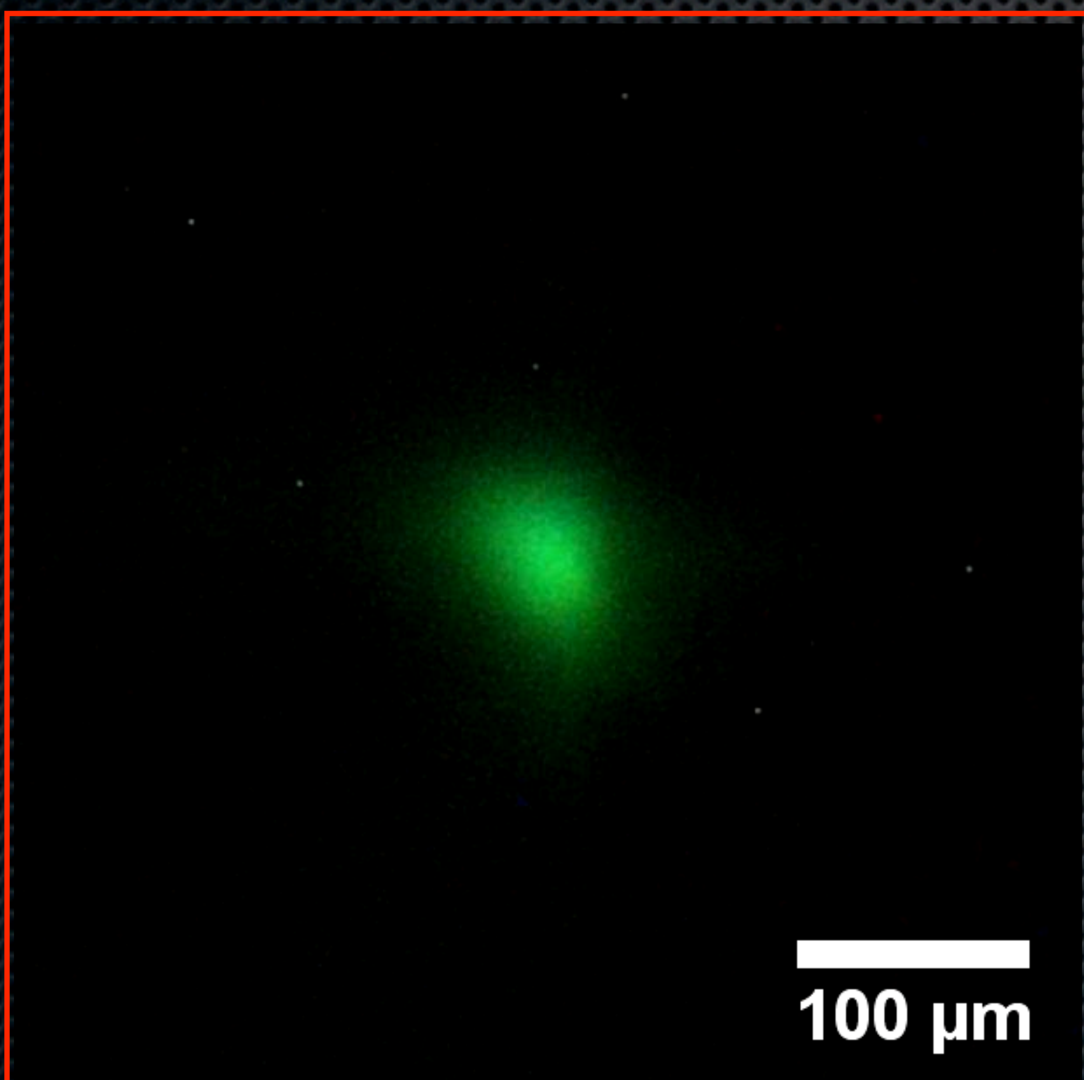
Phosphorus screen and PMMA ablation

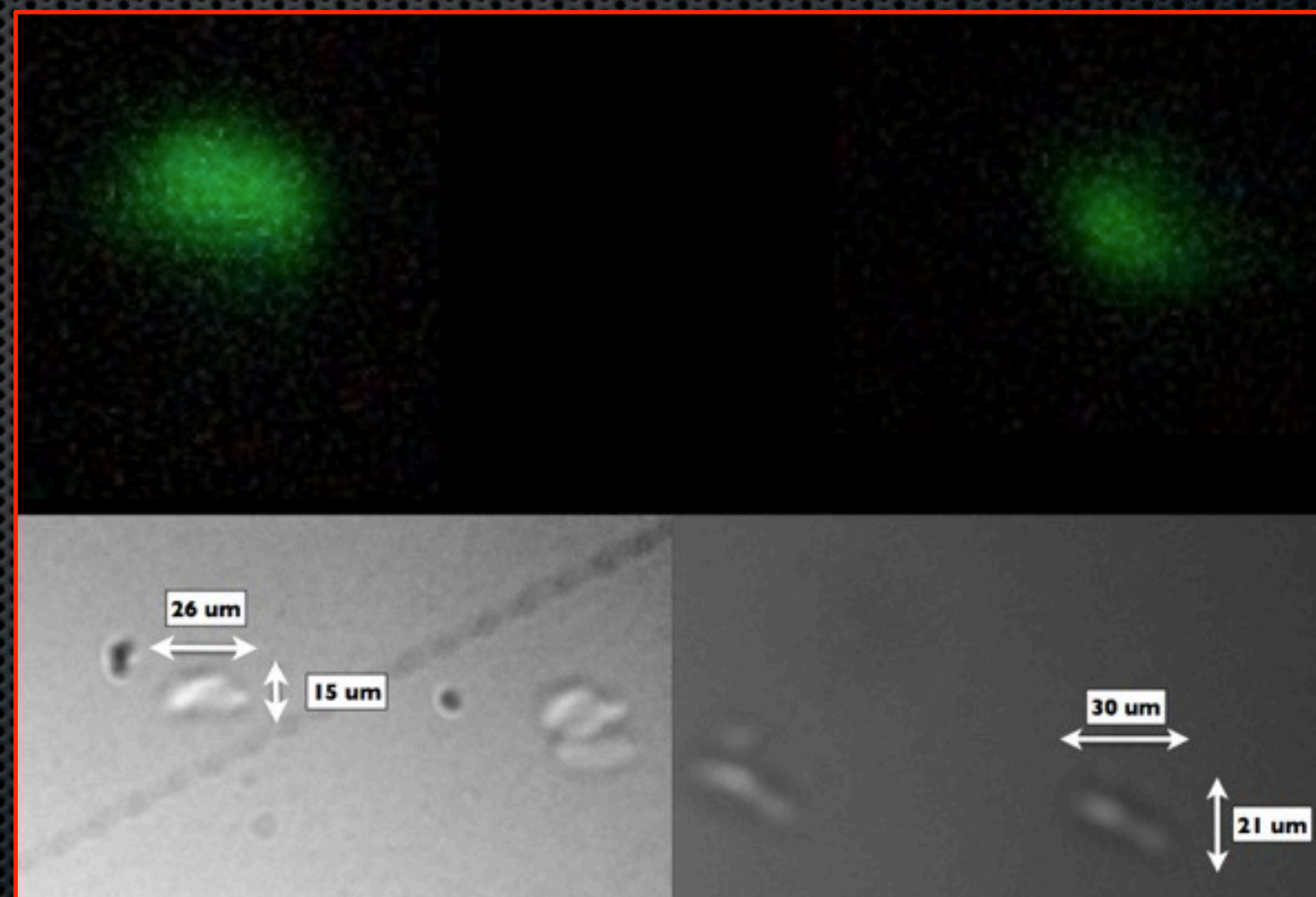
First phase

- rough angle alignment
- optimized mirror bending
- best spot achieved on Phosphorus screen $FWHM_{32nm}$=60x70 μm

Second phase

- refine angle alignment
- optimized mirror bending
- best spot achieved on Phosphorus screen $FWHM_{32nm}$=40x42 μm - seen with PMMA ablation $FWHM_{32nm}$=15x26 μm





Suggestion - Shadow predictions would be a lower limit of the optical system performance

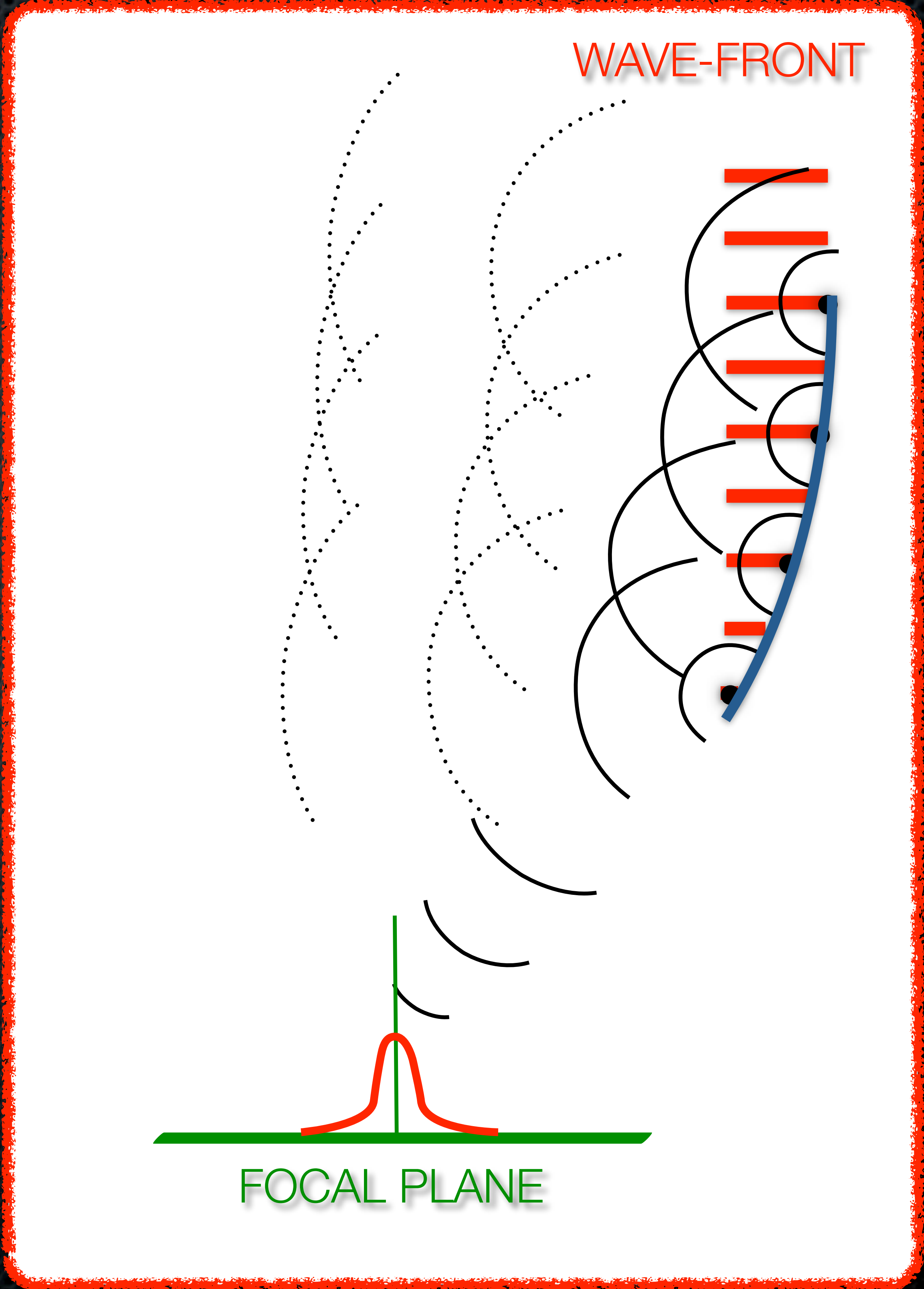
PSF WITH FRESNEL DIFFRACTION

L. Raimondi, D. Spiga, SPIE Proc., 8147 (2010)

- PSF computation from surface metrology
- At any energy
- Approximations:
  - Work in scalar approximation
  - Computation using the meridional profiles (1Dimension)

↓

Work in grazing incidence



PSF WITH FRESNEL DIFFRACTION

L. Raimondi, D. Spiga, SPIE Proc., 8147 (2010)

ELECTRIC FIELD ON THE FOCAL PLANE OBTAINED BY THE CONSTRUCTIVE INTERFERENCE BETWEEN THE SPHERICAL WAVES GENERATED IN EACH POINTS OF THE MIRROR.

Kirchoff-Fresnel diffraction equation

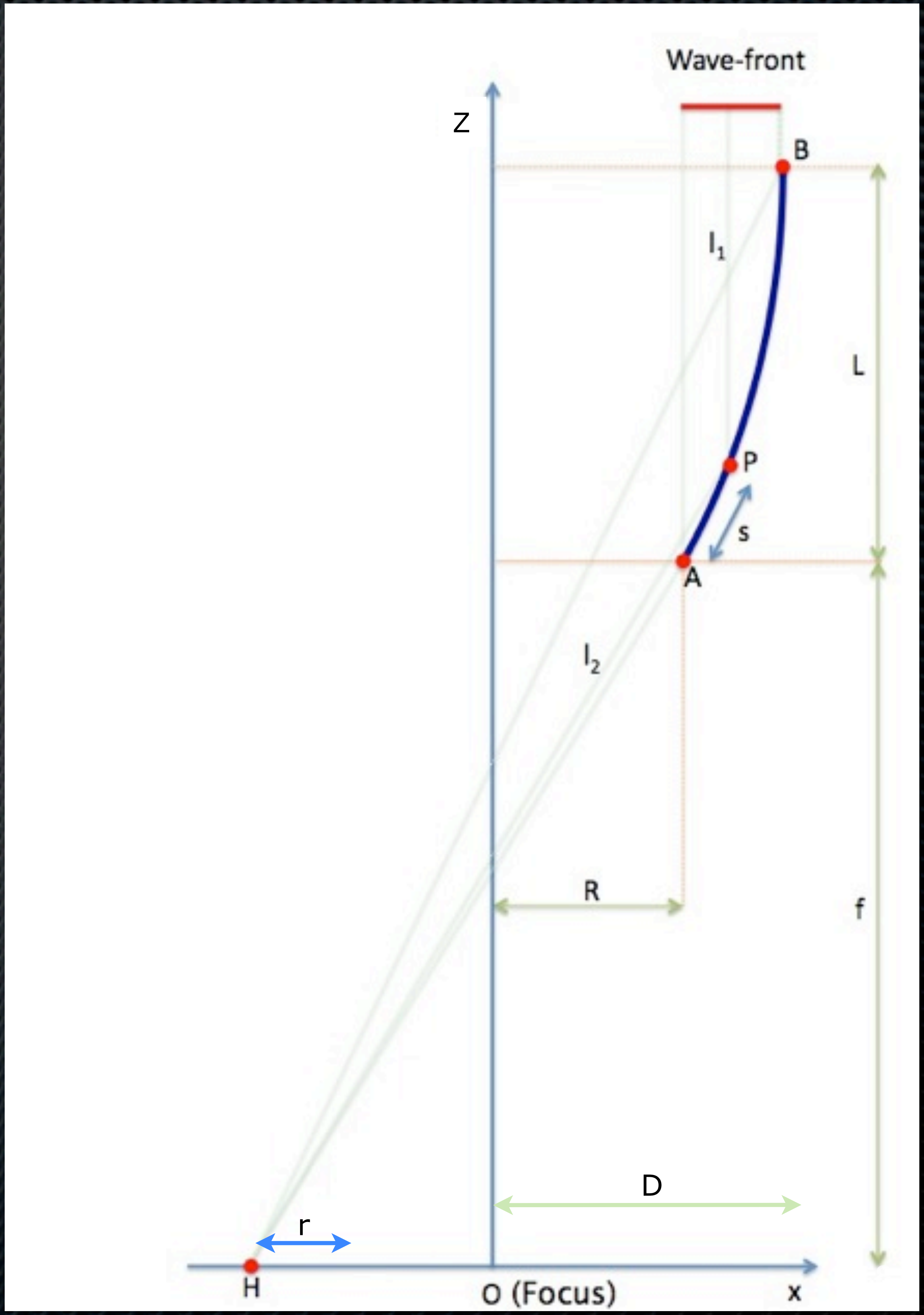
$$U(P) = \frac{Ae^{ikr_0}}{r_0} \int\int_S \frac{e^{iks'}}{s'} K(\chi) dS'$$

$$PSF(x) = \frac{\Delta R}{f \lambda L^2} \left| \sum e^{-i\frac{2\pi}{\lambda}\left(\sqrt{(x-x_{\mathrm{p}})^2 + z_{\mathrm{p}}^2} - z_{\mathrm{p}}\right)} \Delta l \right|^2$$

In order to prevent mirror under sampling:

$$\Delta l \approx \frac{\lambda f^2}{2\pi R_0 r}$$

$$\Delta x \approx \frac{\lambda f^2}{\pi R_0 L}$$

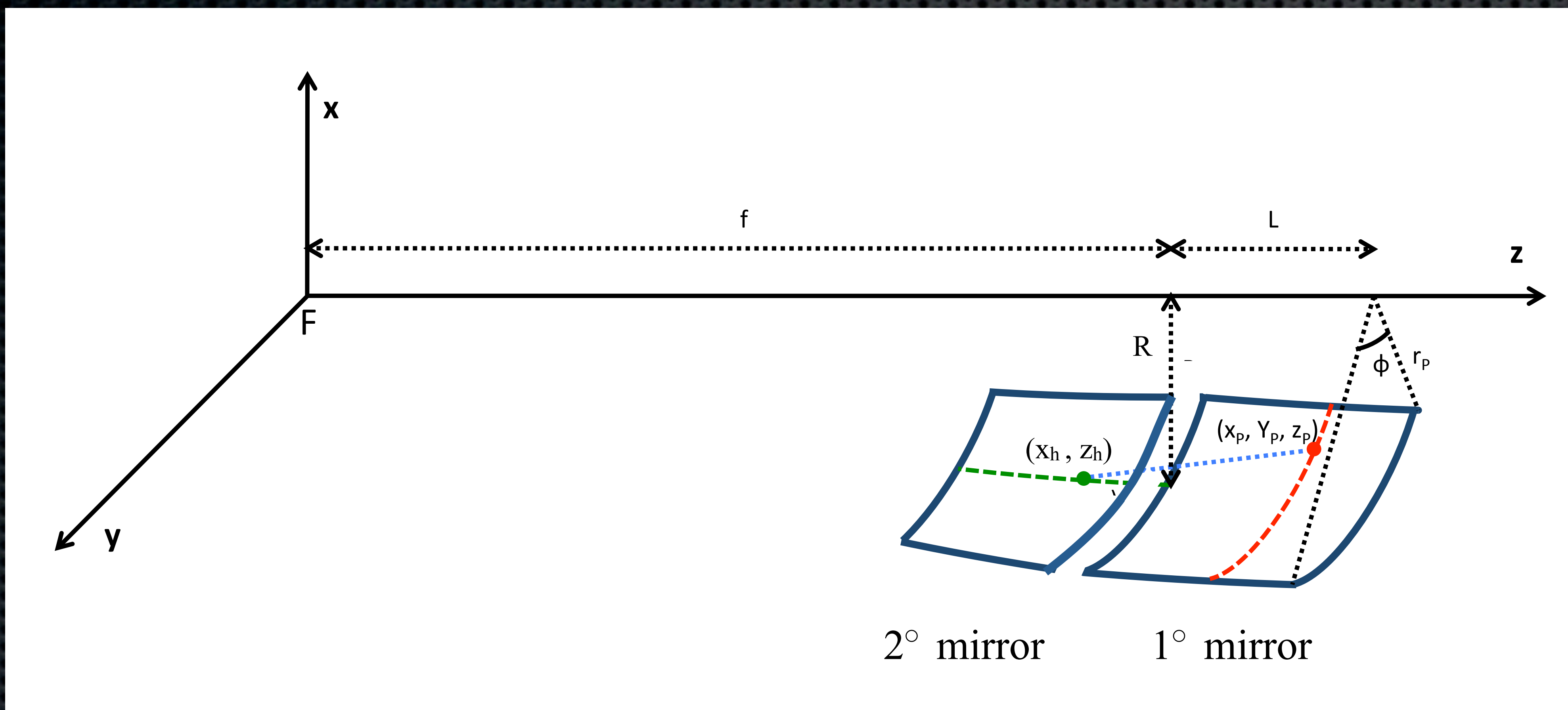


PSF WITH FRESNEL DIFFRACTION

L. Raimondi, D. Spiga, SPIE Proc., 8147 (2011)

Two or more reflections

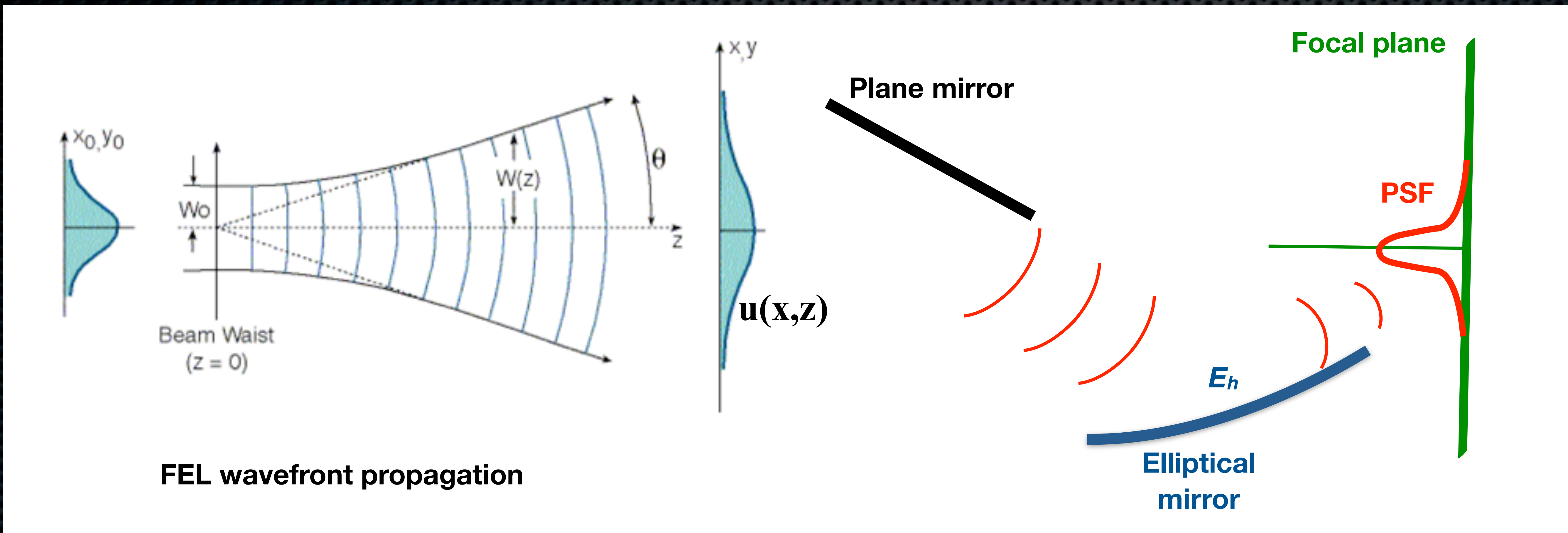
Double reflection



$$E_h(x_h, z_h) = \frac{E_0 \Delta R}{L\sqrt{\lambda x_h}} \int_f^{f+L} \sqrt{\frac{x_p}{d_2}}\, e^{-\frac{2\pi i}{\lambda}(d_2 - z_p)}\, dz_p$$

$$PSF(x) = \frac{\Delta R}{E_0^2 f \lambda L^2} \left| \sum E_h(x_h, z_h)\, e^{-i\frac{2\pi}{\lambda}\left(\sqrt{(x-x_h)^2 + z_h^2}\right)} \Delta l \right|^2$$

Focal spot computation with Fresnel diffraction: FEL case



$$u(x,z) = \frac{\omega_0}{\omega} e^{\left[-j(kz-\Phi)-x^2\left(\frac{1}{\omega^2}+\frac{jk}{2R}\right)\right]}$$

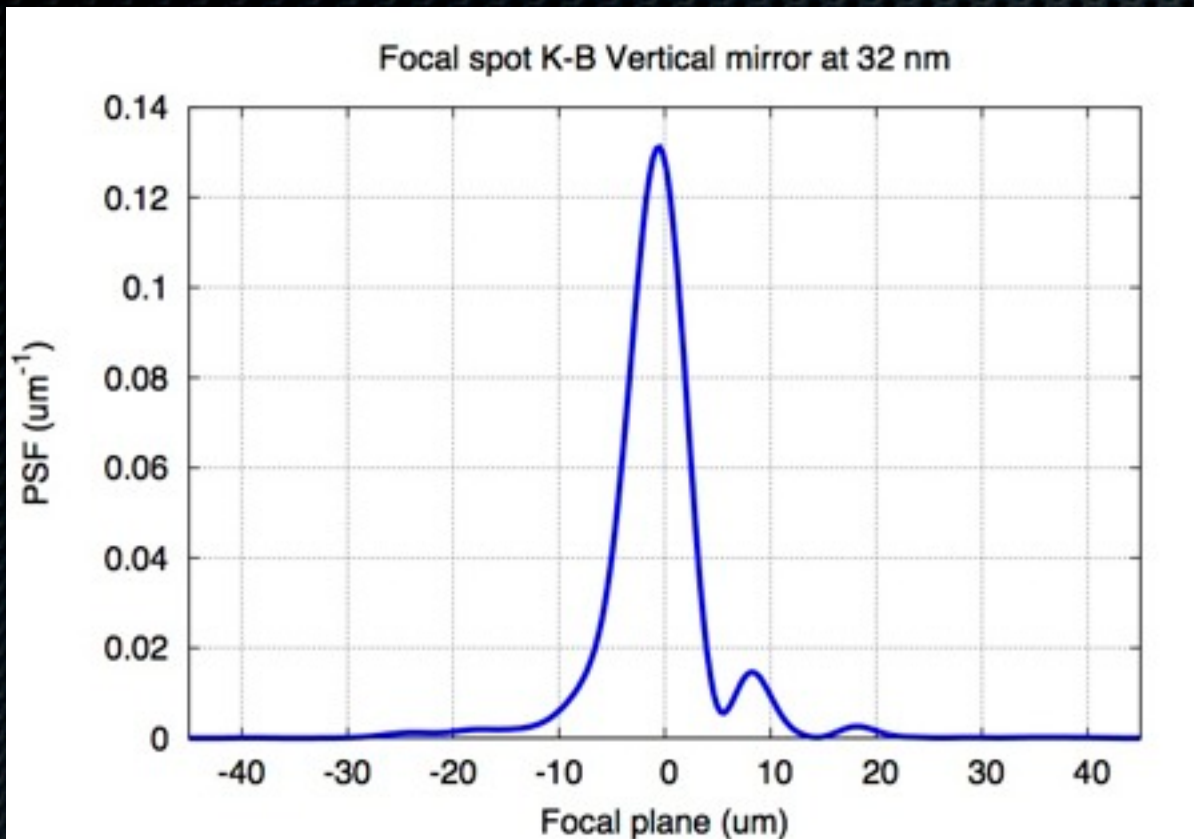
R(z) = wavefront curvature radius

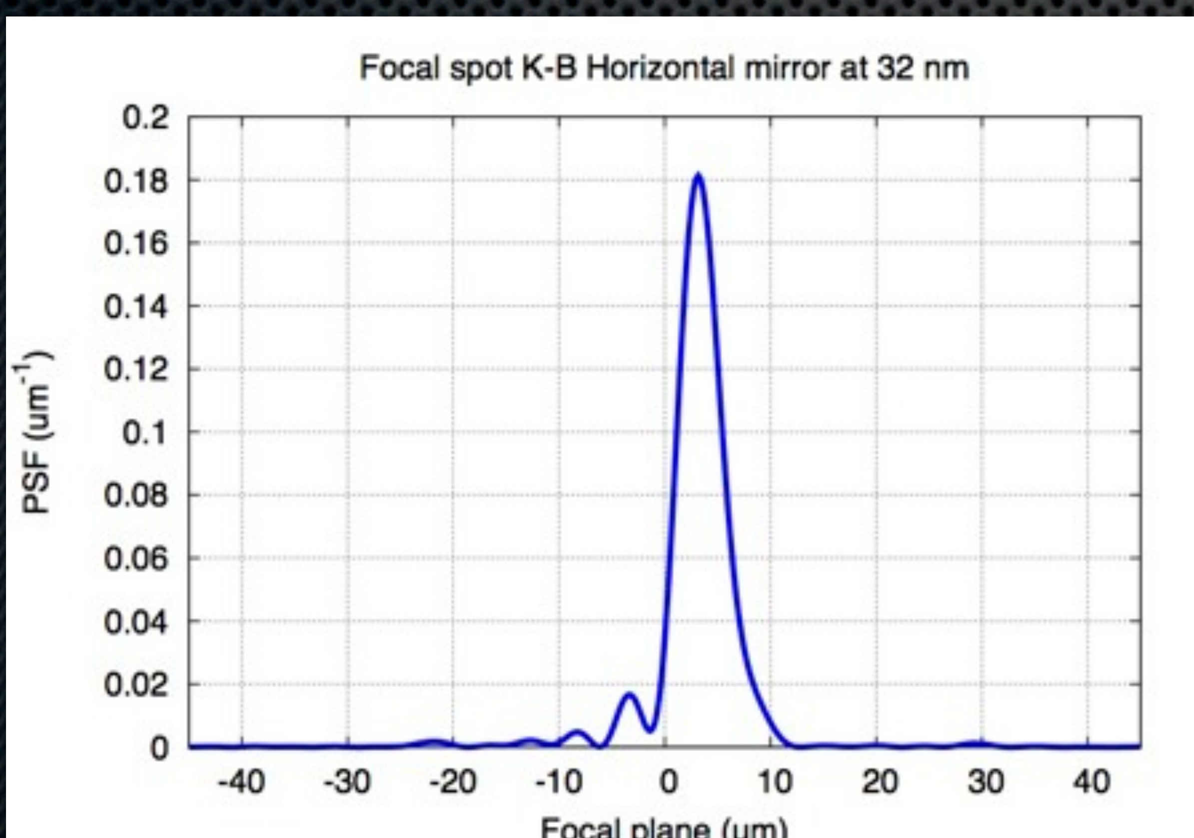
$$k = 2\pi/\lambda \quad \Phi = \arctan(\lambda z/\pi\omega_0^2)$$

$$E_h(x_h, z_h) = \frac{E_0 \Delta R}{L\sqrt{\lambda x_h}} \int_f^{f+L} u(x,z) \sqrt{\frac{x_p}{d_2}}\, e^{-\frac{2\pi i}{\lambda}(d_2 - z_p)}\, dz_p$$

$$PSF(x) = \frac{\Delta R}{E_0^2 f \lambda L^2} \left| \sum E_h(x_h, z_h) e^{-i\frac{2\pi}{\lambda}\left(\sqrt{(x-x_h)^2+z_h^2}\right)} \Delta l \right|^2$$

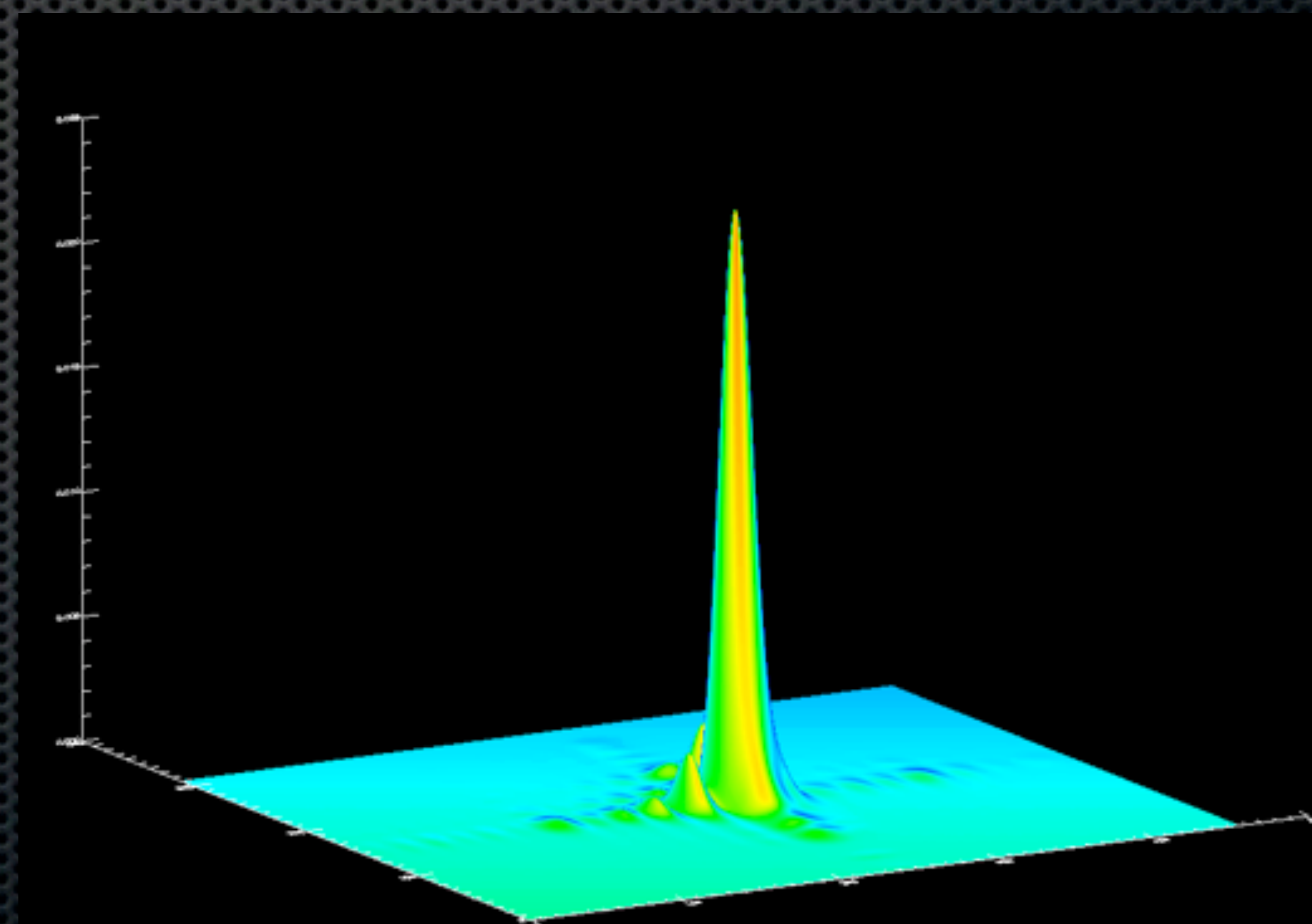
Focal spot simulations - DiProI





32 nm wavelenght

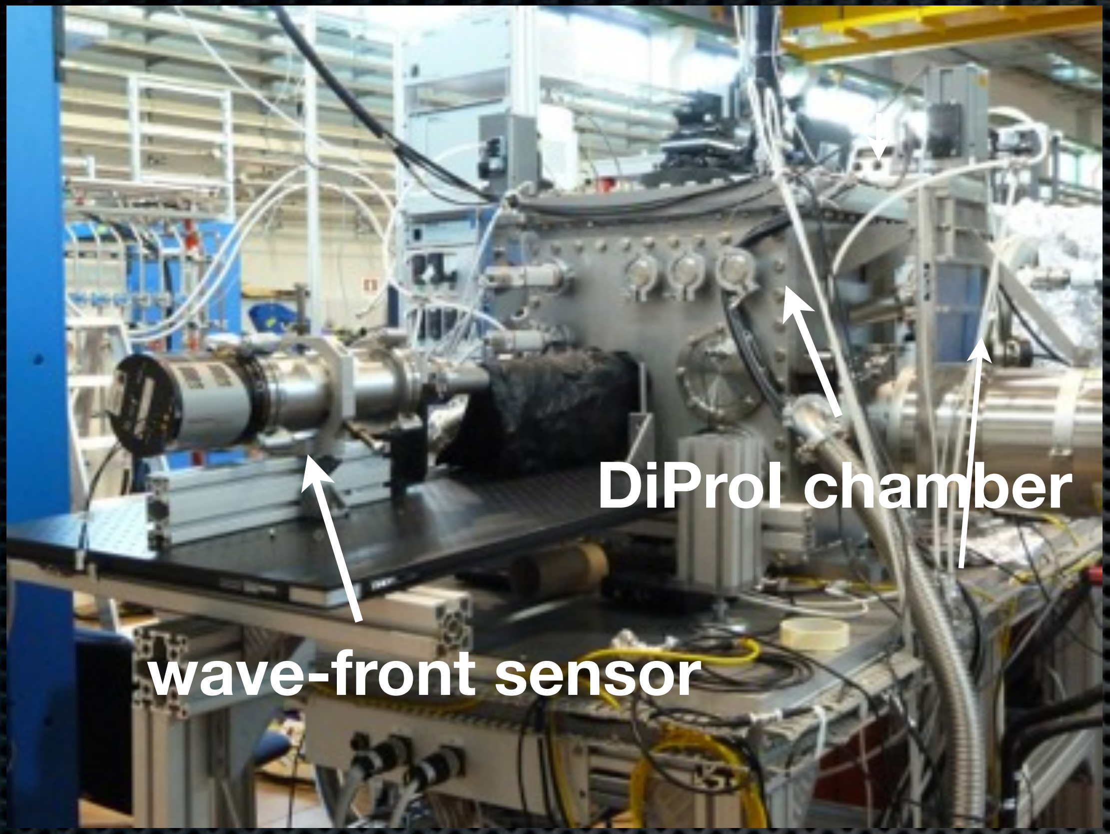
- K-B vertical best focus -2 mm from nominal $FWHM_{32nm}$ = 5.8 μm
- K-B horizontal best focus 0 mm from nominal $FWHM_{32nm}$ = 4.4 μm

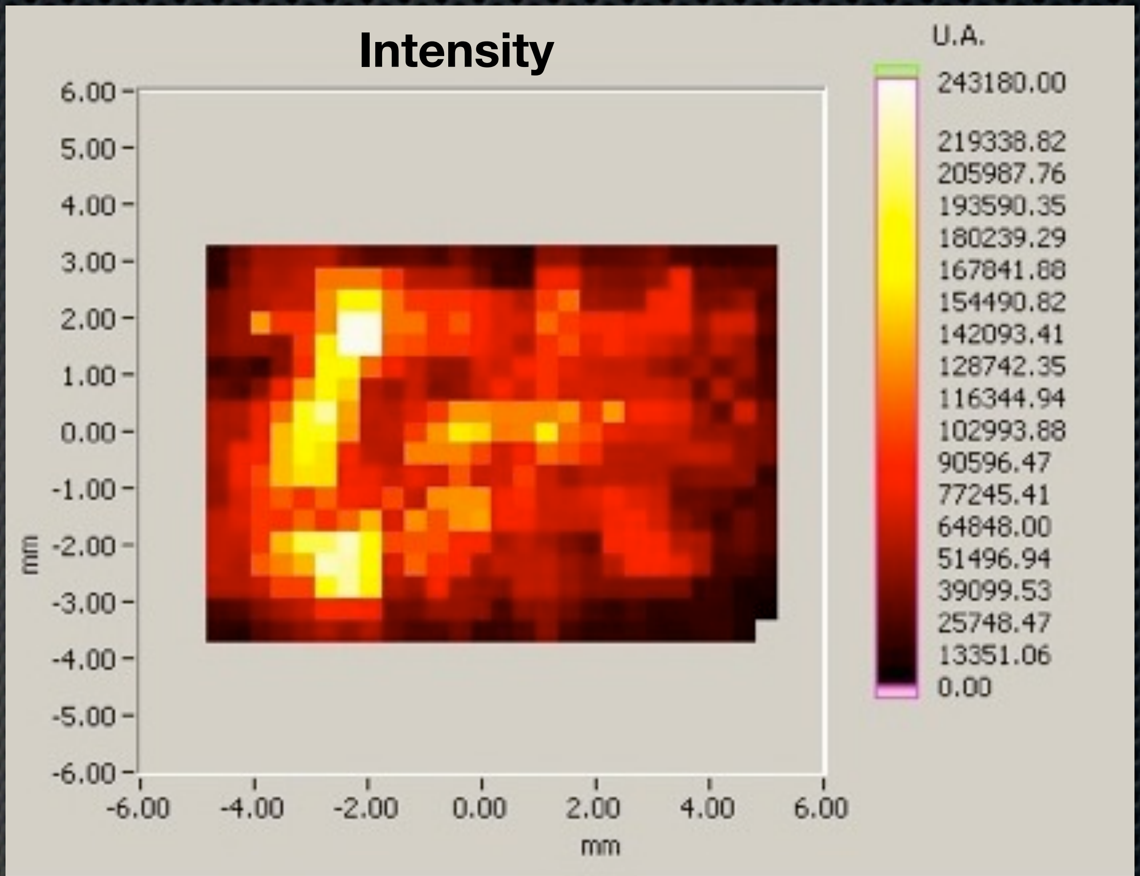


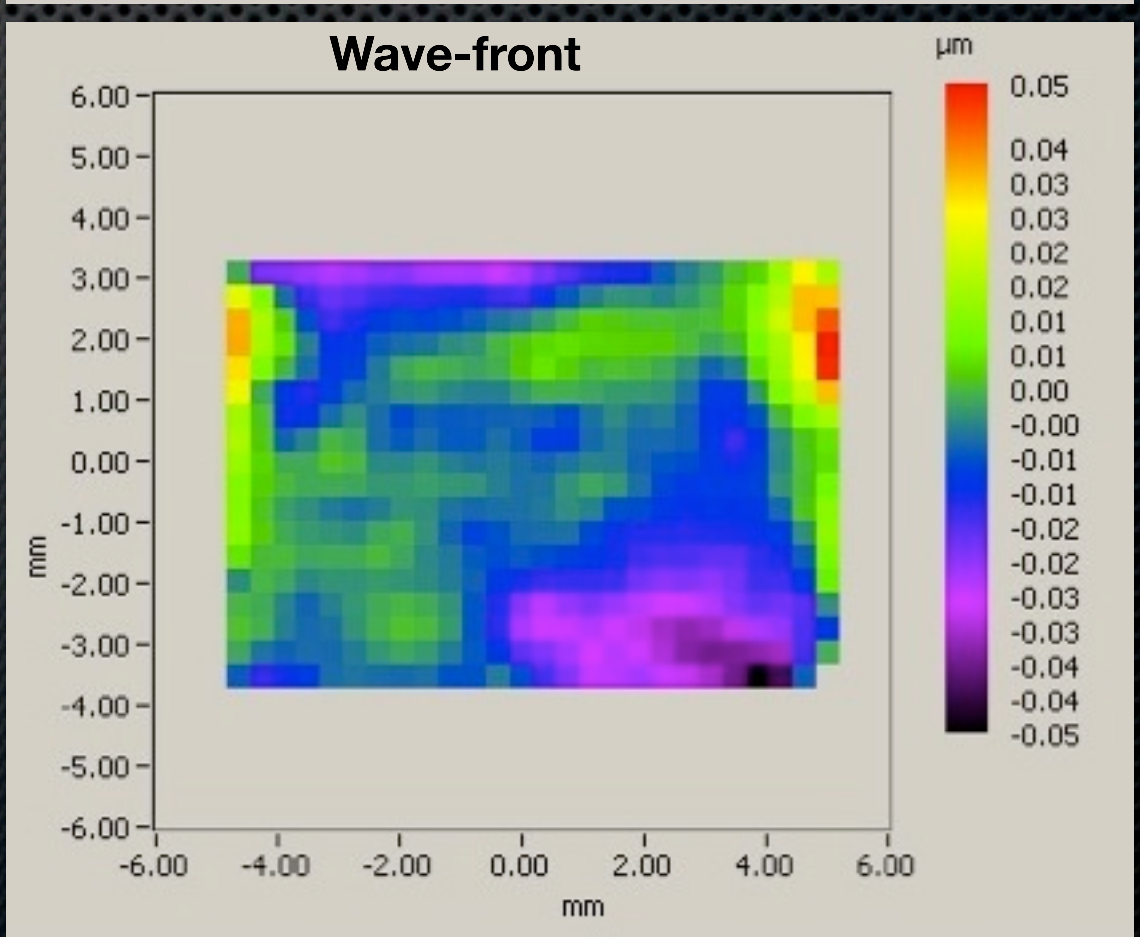
Suggestion - the system limit in terms of the spot size should be lower than shadow predictions

Focal spot measurements at DiProI end-station

Wave-front sensor measurements



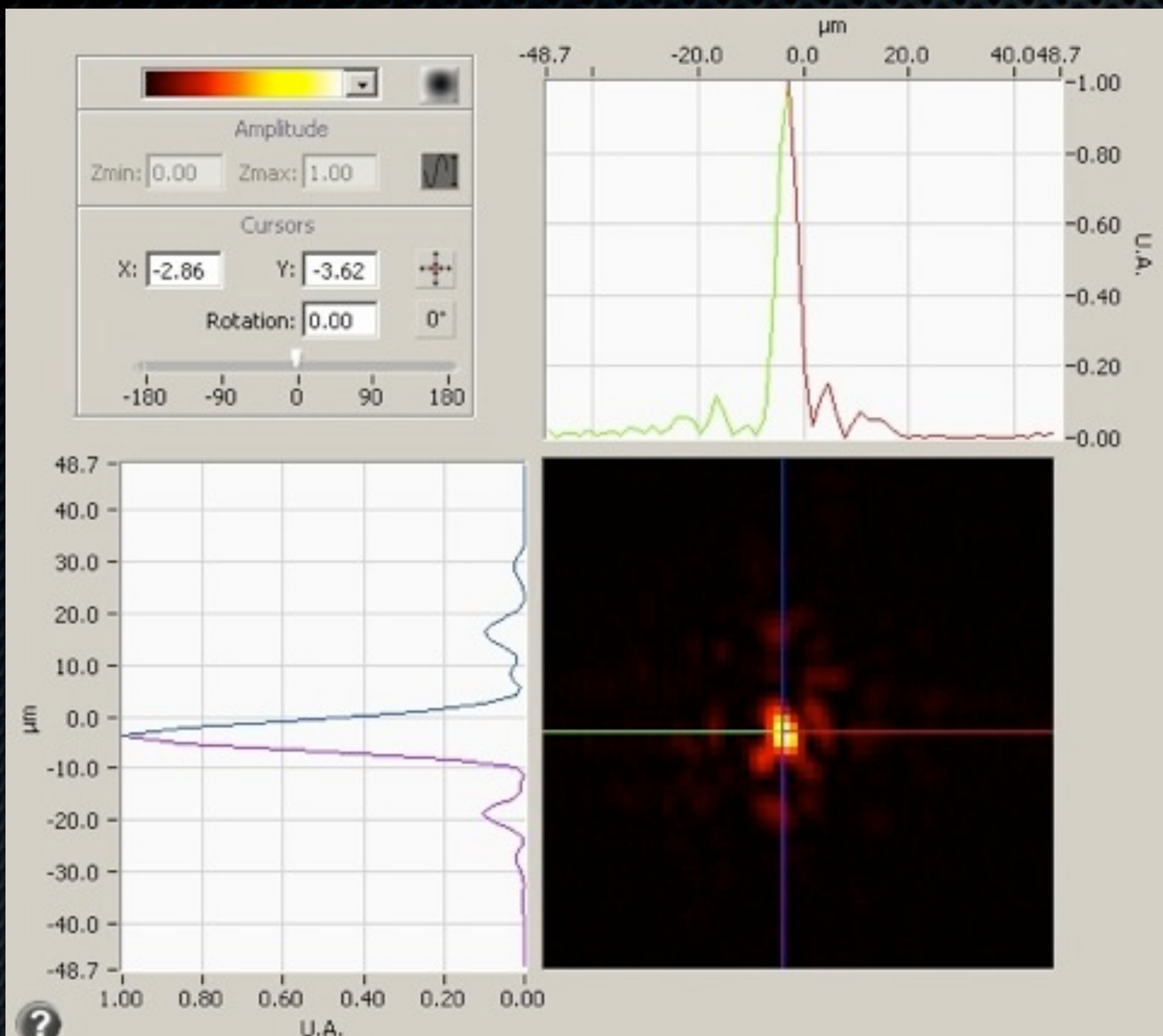




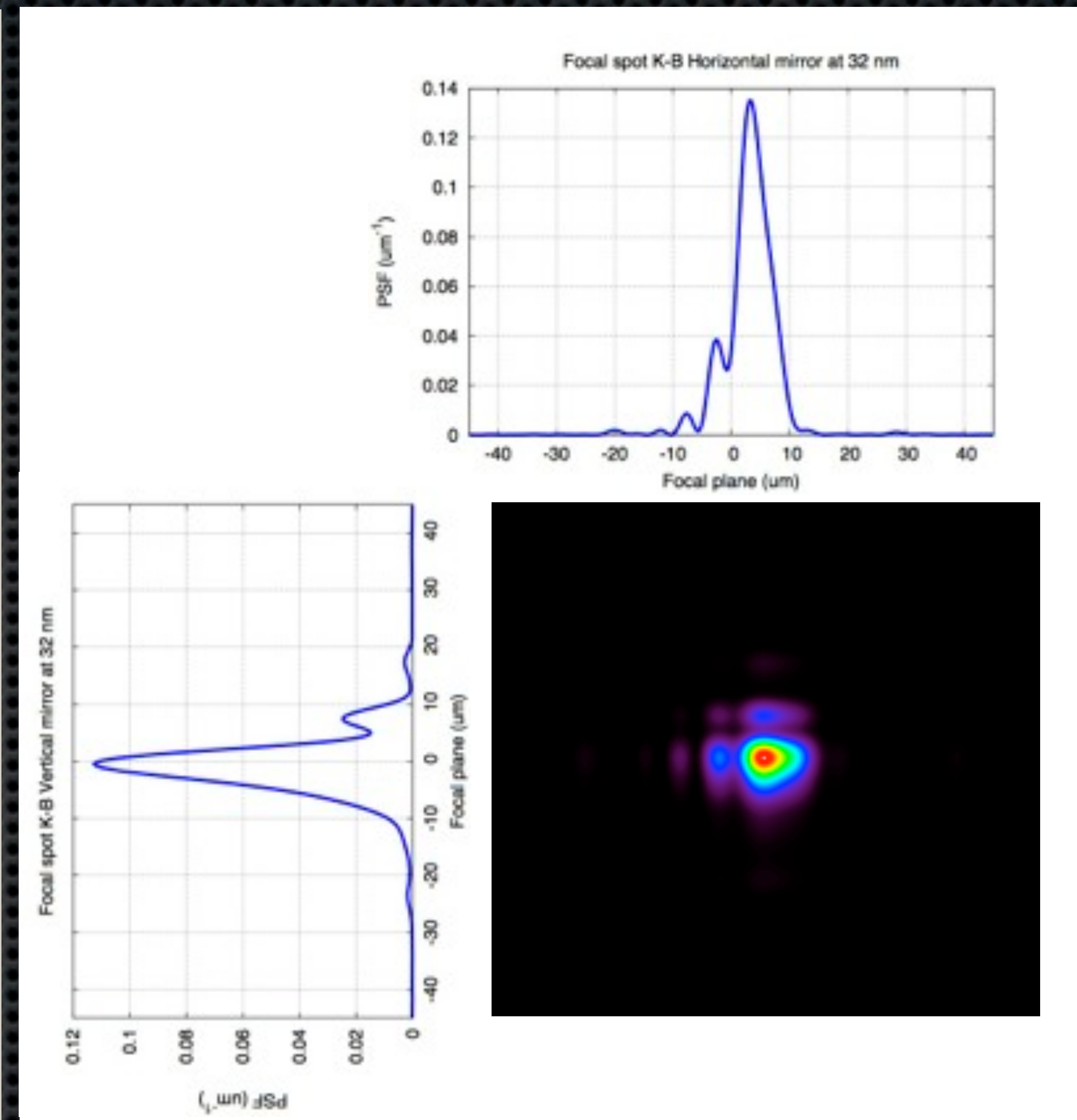
- FEL 1
- wavelength - 32 nm
- measuring of Intensity and Wave-front at 1m out of nominal focus
- reconstruction of the spot in focal plane

Focal spot measurements - DiProl

Wave-front sensor measurements



Fresnel diffraction simulations



- FEL 1
- wavelength - 32 nm
- diffraction limit spot-size at 32 nm FWHM = 4x5 µm
- Best spot-size measured FWHM = 5x8 µm

- Spot-size simulated with ray-tracing FWHM = 10.5x18 µm
- Spot-size simulated with Fresnel diffraction at the common best focus (-1mm from the nominal focus) FWHM = 5.2x7.7 µm

FUTURE WORK

- Characterization of the FEL wavefront by measuring the electric field with the wavefront sensor before K-B optics
- Put the measured electric field in the simulator - evaluation of the performances of the optics (degradation/improvement of the wavefront)
- Implementation of the K-B system: new anti-twisting mounting - piezo-electric actuators for mirror shape correction

CONCLUSIONS

- We performed surface profile characterization of the K-B bendable system mounted in the DiProI chamber with Long Trace Profilometer.
- We extended the Fresnel diffraction method to FEL applications - non isotropic sources - focal spot given the best measured profile at LTP - FWHM = 4.4x7.7 μm
- We provided several measurement campaigns of K-B system focalization in the DiProi end-station, 40x42 μm on the P-screen 15x26 μm on PMMA
- Through a wave-front sensor we went further in the optimization of the mirror shape. Focal spot (reconstructed via software) FWHM = 5x8 μm
- From the comparison between simulations and measures we conclude that the focal spot in a FEL can now be predicted by using the Fresnel diffraction method.

People involved in this work:

- L.Raimondi, N.Mahne, C.Svetina, S.Gerusina, C.Fava, L. Rumiz, R.Gobessi and M.Zangrando – PADReS
- F.Capotondi, E.Pedersoli, M.Kiskinova – DiProI
- G.Sostero – Metrology LAB
- D.Cocco – SLAC
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THANKS FOR YOUR ATTENTION